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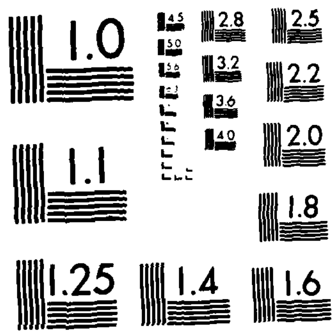

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

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Technical Memorandum

THE ARCTIC CHANNEL: AN ACOUSTIC WAVEGUIDE*

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ABSTRACT

The Arctic Basin provides a unique channel for acoustic propagation. The two features peculiar to the polar environment that most strongly influence the transmission of underwater sound are the permanent ice cover and the uniform sound speed structure. As a result, only a few low order modes will propagate through it to great distances and the non-linear frequency dependent time delay of the channel may be accurately computed. In the Arctic channel, the dispersion is such as to produce a "chirp" frequency modulation on a transmitted pulse. Consequently the channel itself may be used as the matched receiving filter by transmitting a time reversed ("chirp") waveform and letting the dispersion effect compress the waveform. This process will be strictly range dependent.

ADMINISTRATIVE INFORMATION

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In this paper, the feasibility of exploiting the unique characteristics of the Arctic Basin to permit optimum signal waveform design and receiver processing is examined.

The approach is based upon:

1. The ability to accurately predict the unique propagation behavior in the Arctic Basin, and

2. The exploitation of pulse compression techniques to realize match filter processing with simple broadband filter hardware.

The reason why accurate predictions are critical to the success of the scheme will become evident shortly. For the present, we discuss the manner in which these predictions are obtained from the fast field program (FFP). This can be briefly summarized in terms of the two equations shown in figure 1. The received pressure field versus time and range, at a fixed depth is obtained from the first equation by evaluating: the Fourier transform over frequency of the product of the function, H, which is the transfer of the ocean and the function, F, the spectrum of the source signal. Before this can be done, however, the transfer function must be obtained from the Fourier-Bessel transform, shown as the second equation, for each frequency of interest. Both integrals are evaluated numerically with a minimum number of approximations via the fast Fourier transform. The solution is straightforward but does involve a significant amount of computer time and poses a problem in data management.

An explanation is in order concerning the justification of applying a deterministic, range independent model in the Arctic which is environmentally range dependent.

The experimental waveforms from explosives, detonated and received at the same depth, but at different range separations and over slightly different tracks is shown in figure 2 along with the associated bathymetry. One would expect that energy arriving at the beginning of the waveform, which travels via deep refracted paths, would be influenced by bathymetry. An examination of the waveforms indicates this to be the case. However, the last group of arrivals, which occurs between 8-9 seconds, travels along paths trapped near the ocean surface and should not be effected by changes in Bathymetry. It can be seen that this last group of arrivals is qualitatively at least the same in each case. These arrivals can be associated with the lowest order modes which propagate at very low frequencies. Because the frequency content of the other arrivals is higher, they suffer considerable scattering from the rough under ice canopy in addition to the effects caused by the changing Bathymetry and do not propagate to long ranges. Thus, if the source waveform is limited to very low frequencies, the range independent model should provide accurate predictions even though the environment is range dependent. Quantitative comparisons of prediction from the range independent model and experimental data are presented in figure 3 and figure 4. A comparison between computed and experimental amplitudes of the first mode at 20 and 40 Hz is provided in figure 3. In addition to the excellent agreement, it also provides evidence of the previously mentioned fact that at these frequencies the energy is trapped near the surface and thus will not be effected by changes in bathmetry. A comparison is shown in figure 4 between the predicted group velocity dispersion for the first three modes, represented by the solid line and experimental values. Similar comparisons have been made with data collected over a 20 year period in the Arctic at environmentally diverse locations. The distinct dispersion character shown persists in all cases.

The pulse compression technique was originally developed for radar systems to obtain high range resolution with long pulses. In that application, the frequency of the transmitted pulse is varied with time to produce a wideband waveform. A matched filter is then implemented at the receiver by passing the waveform through a filter with the inverse frequency versus time relationship. All frequency components of the pulse are thus properly delayed and appear simultaneously at the output to produce a pulse of shorter duration and high peak amplitude.[1]

The technique was first used in underwater acoustics by Clay and Parvalescu to examine signal transmission stability in Tongue of the Ocean.[2] Their experiments were performed at 400 Hz in 1.8 km of water at a range of 36 km. They discovered that the signal enhancement was realizable but sensitive to geometry (source and receiver depth variations). The Arctic offers an extraordinarily better channel (a few modes at 20 Hz versus a few "tens" of modes at 400 Hz) for the application of this scheme.

The dispersion in the Arctic channel is such as to produce a chirp frequency modulation on a transmitted pulse. Since this effect can be accurately predicted, the channel itself may be used as the receiving filter. This is accomplished by first predicting what the received waveform would be at a given range. In the example shown, figure 5, the waveforms resulting from a single cycle of an 8 Hz sine wave are shown at 300, 400, and 500 Km from top to bottom respectively.

The first and second modes are clearly distinguishable and the dispersion evidenced in these simulations was used in the comparison with experimental values shown previously.

If pulse compression is desired at 400 Km, the middle waveform would be reversed in time and used as the source waveform.

The results of transmitting the time reversed version of the 400 Km signal to the ranges 300, 400 and 500 Km, from top to bottom respectively, are shown in figure 6.

An examination of the result at the matched range, appearing in the middle, does indeed show that the desired result has been obtained.

The degradation with range of the time reversed waveform is graphically depicted in figure 7 by plotting the peak amplitude of the received waveform versus range. With no special signal shaping the peak amplitude would decay with range according to 20 log R. This is due to the combined effects of cyclindrical spreading and also a stretching of the waveform in time. The initial decay of the peak amplitude with range for the time reversed signal is seen to obey a 10 log R dependence. This occurs because as the range increases the pulse is trying to compress itself and one is left with only cyclindrical spreading. Beyond the matched range, the pulse again begins to spread in time and the peak amplitude obeys the 20 log R decay law.

SUMMARY

The Arctic basin provides a unique channel for acoustic propagation. The presence of a rough ice canopy in conjunction with a generally increasing sound speed versus depth profile, which is uniform in range and time, permits only very low frequencies to propagate to great distances. The low frequencies are trapped near the ocean surface and not influenced by changes in bathymetry. Under these conditions, accurate predictions of the received waveform can be made, leading to the design of an optimum transmitted signal by utilizing the ocean as a matched filter.

REFERENCES

1. Walther, "Pulse Compression in an Acoustic Waveguide", JASA, Vol 33 No. 5, May 1961.

2. Parvalescu and Clay "Radio Electric Engineering", 29: p8.223 (1965)

Direct Solution

- Source Characteristics and Environment Given
- Solution for Received Pressure Field vr Range Desired

$$\tilde{P}_R(r,z,t) = \int_{-\infty}^{\infty} \underbrace{H(r,z,f)}_{\substack{\text{Transfer} \\ \text{Function}}} \quad \underbrace{F(f)}_{\substack{\text{Source} \\ \text{Spectrum}}} \quad e^{-i2\pi ft} df$$

$$H(r,z,f) = \int_{0}^{\infty} 2G(z_s, z; \xi, f) J_0(\xi r) \xi \, d\xi$$

FIGURE 1

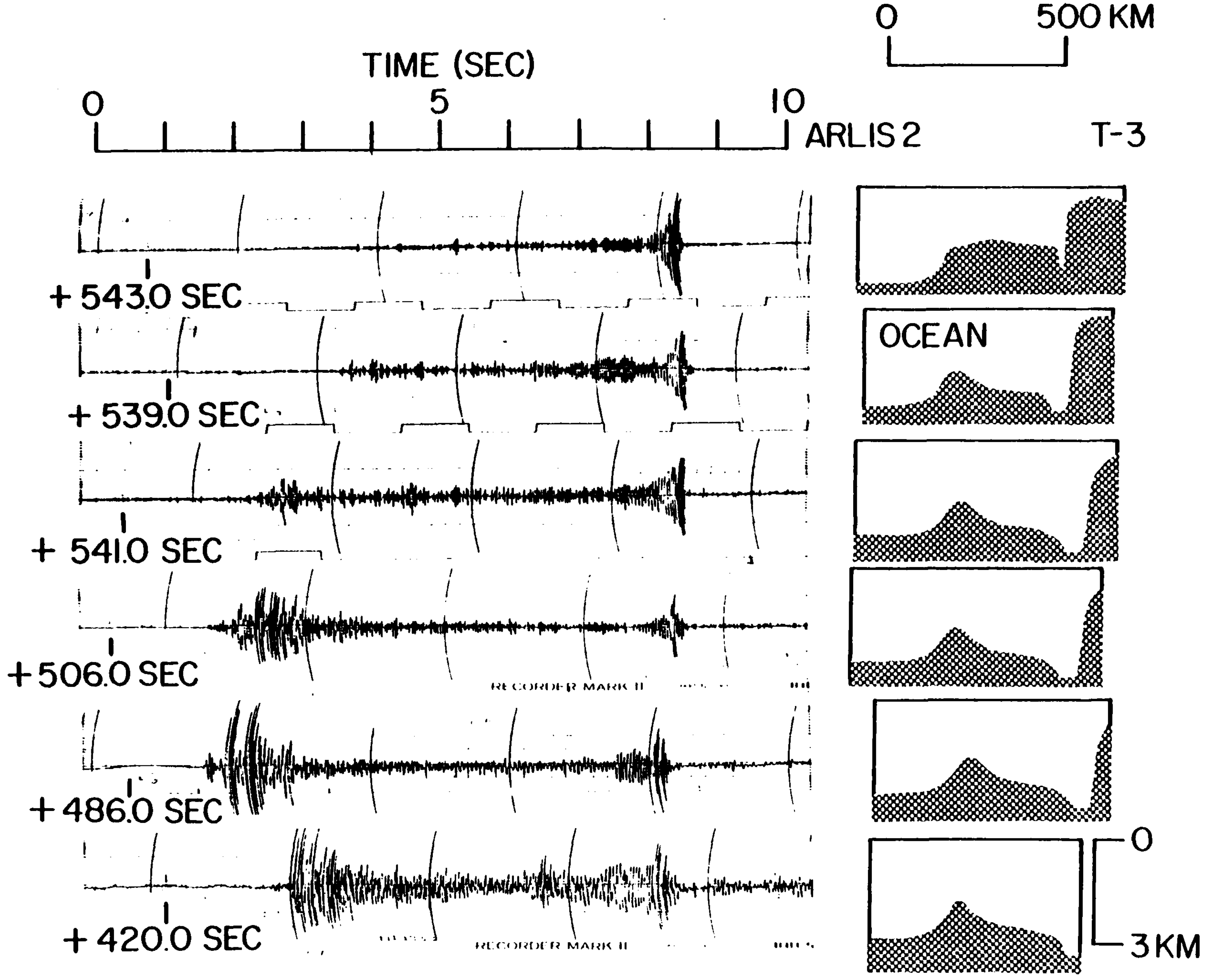
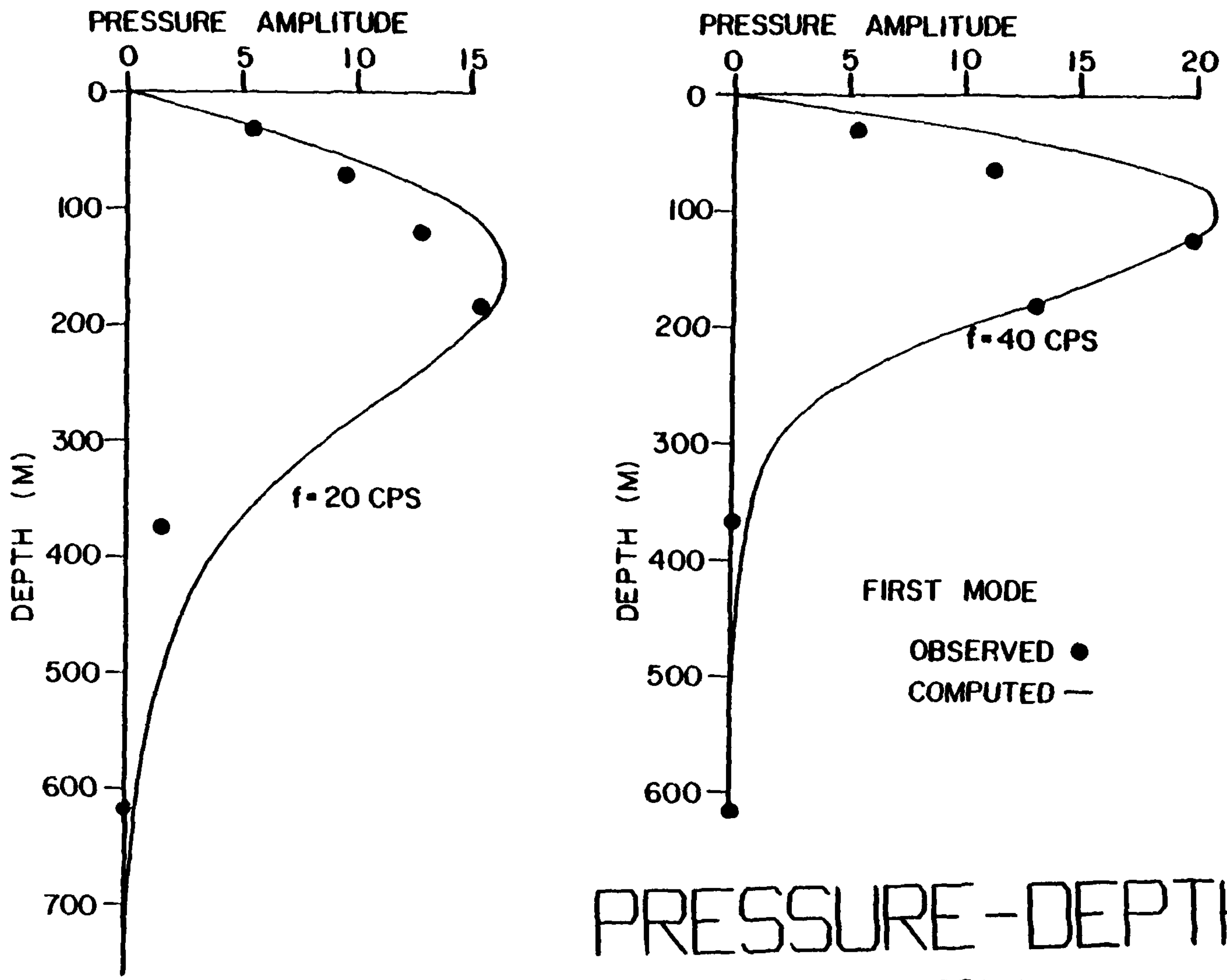

0
500 KM
TIME (SEC)
0
5
10
ARLIS 2
T-3
+ 543.0 SEC
+ 539.0 SEC
+ 541.0 SEC
+ 506.0 SEC
+ 486.0 SEC
+ 420.0 SEC
OCEAN
0
3 KM

FIGURE 2



PRESSURE-DEPTH VARIATION

FIGURE 3

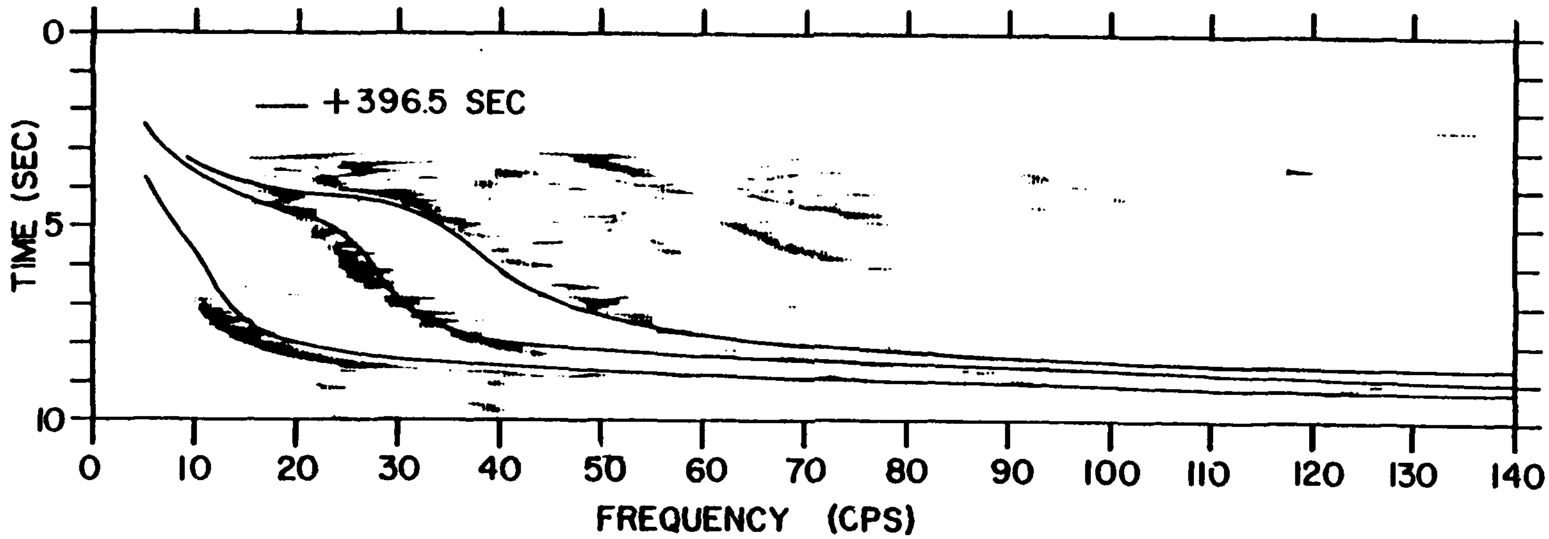

+396.5 SEC
TIME (SEC)
0
5
10
FREQUENCY (CPS)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140

FIGURE 4

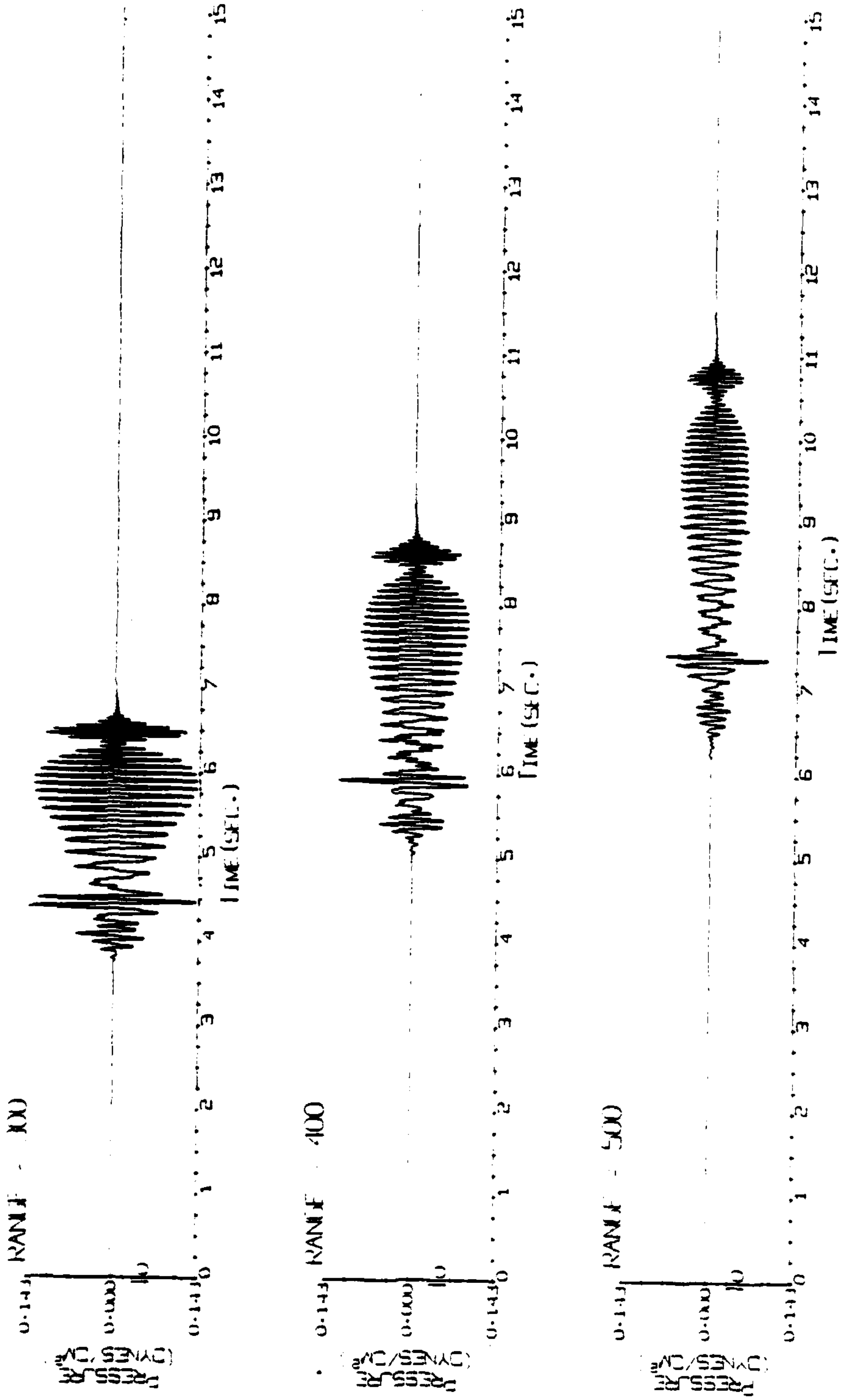


FIGURE 5

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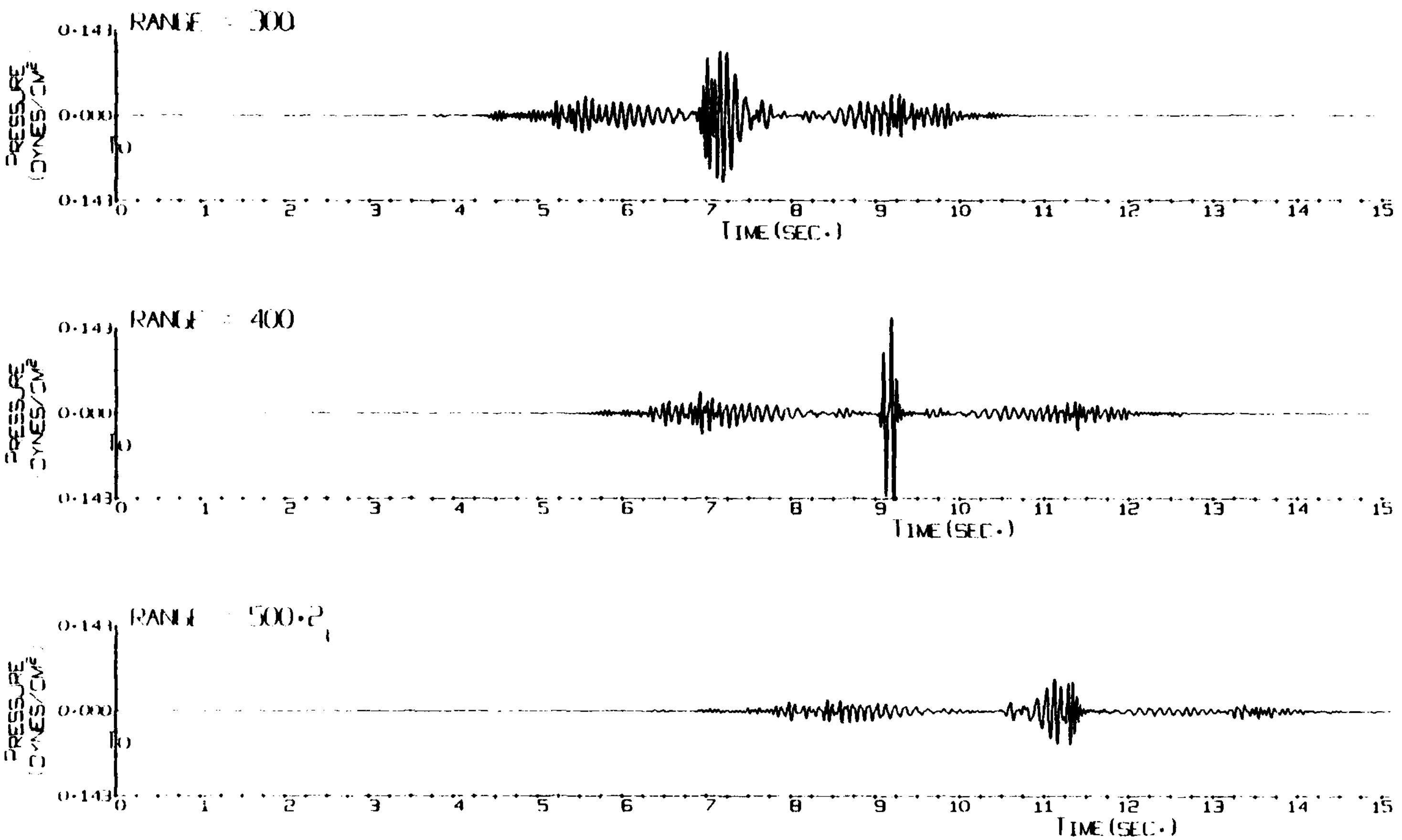

FIGURE 6

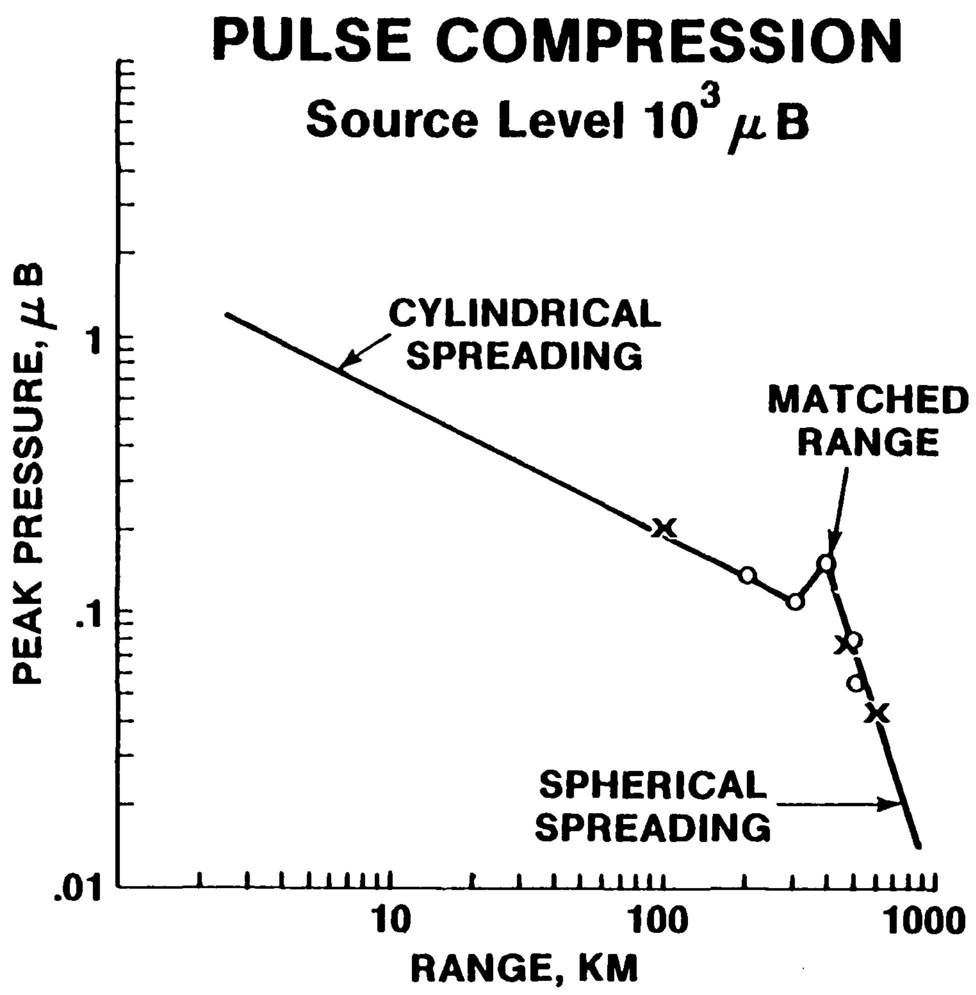
PULSE COMPRESSION
Source Level 10^3 μB
PEAK PRESSURE, μB
1
.1
.01
CYLINDRICAL SPREADING
MATCHED RANGE
SPHERICAL SPREADING
10
100
1000
RANGE, KM

FIGURE 7

END

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